CHAPTER 2

Characteristics of Sewage Sludge and Biosolids

INTRODUCTION

The characteristics of biosolids play an important part in their use for land application. They can be broken down into three categories: physical, chemical, and biological. Physical properties affect the method of application, as well as the soil's physical and chemical properties. Several of these physical properties have an important effect on plant growth. They can affect the availability and accumulation of plant nutrients and trace elements. The important physical characteristics are:

- Solid content
- Organic matter content

Chemical properties affect plant growth as well as the soil's chemical and physical properties. The important chemical characteristics are:

- pH
- Soluble salts
- Plant nutrients — macro and micro
- Essential and non-essential trace elements to humans and animals
- Organic chemicals

Biological properties affect the soil's microbial population and organic matter's decomposition in soil. Biological characteristics also affect human health and the environment. All biosolids contain a wide variety of microbes. Many of these are very beneficial, while others can be harmful to humans, animals, or plants. The microbial population in biosolids is very important to the decomposition of organic matter. Since pathogens represent the most important microbial biosolids property for land application, this topic is covered in a separate chapter.

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PHYSICAL PROPERTIES

The solids content of biosolids affects the method of land application. Liquid or low-solids biosolids will generally be injected into the soil to prevent vectors and provide better aesthetics. Vector reduction is part of the USEPA 40 CFR 503 regulations. The addition of liquid biosolids also increases the moisture content of the soil, which could benefit plant growth. The organic matter content is diluted and consequently its benefit in improving soil structure will occur only after repeated applications and after a long period of time. The amount of plant nutrients and trace elements depends on the quantity and percent solids of the biosolids.

Dewatered or semisolid biosolids are usually spread on the surface and subsequently plowed into the soil. The concentration of solids adds organic matter to the soil. This added organic matter improves the soil's physical properties, especially soil structure, soil moisture retention, soil moisture content, and cation exchange capacity. The dark content of the added organic matter could affect soil surface temperatures and in the spring hasten germination of crops. High solid biosolids are usually compost or heat-dried products. Compost is an excellent source of organic matter and will improve the soil's physical properties (Epstein, 1997), which include:

- Soil structure — bulk density, porosity, soil strength, and aeration (by increasing soil aggregation)
- Soil water relationships — water retention, available water to plants, and soil water content
- Water infiltration and permeability
- Soil erosion and runoff
- Soil temperature

Heat-dried products are generally applied as fertilizers and add little organic matter since small amounts are applied. They do not usually affect the soil's physical properties.

The organic content of biosolids will vary, depending on the solids content and extent of treatment. Organic matter in biosolids can be as high as 70% depending on the wastewater treatment (e.g., digestion, bulking agent addition in the case of compost, lime addition, and addition of other materials).

CHEMICAL PROPERTIES

The chemical properties of biosolids are affected by several factors:

- Quality of wastewater — extent of industrial pretreatment
- Extent of treatment — primary, secondary, tertiary
- Process modes — use of chemicals (e.g., ferric chloride, polymers, etc.)
- Methods of stabilization (e.g., lime treatment)

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Table 2.1 Changes in Heavy Metal Concentration

Heavy Metal	Mean Concentration 40 Cities[1] mg/kg, dry wt.	Mean Concentration NSSS[2] Mg/kg, dry wt.	Part 503 Pollutant Concentration Limits mg/kg, dry wt.
Arsenic (As)	6.7	9.9	41
Cadmium (Cd)	69	6.94	39
Chromium (Cr)	429	119	1,200
Copper (Cu)	602	741	1,500
Lead (Pb)	369	134.4	300
Mercury (Hg)	2.8	5.2	17
Molybdenum (Mo)	18	9.2	–
Nickel (Ni)	135	42.7	420
Selenium (Se)	7.3	5.2	36
Zinc (Zn)	1,594	1,202	2,800

[1] USEPA, 1989.
[2] National Sewage Sludge Survey (USEPA, 1990).

Table 2.2 Trends in Metal Concentration of Sewage Sludge/Biosolids from 1976 to 1996

Year	As	Cd	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn
1976[1]	–	110	2620	1210	1360	–	–	320	–	2790
1979[2]	6.7	69	429	602	369	2.8	18	135	7.3	1594
1987[3]	12	26	430	711	308	3.3	19	167	6.0	1540
1988[4]	9.9	6.9	119	741	134	5.2	9.2	43	5.2	1202
1996[5]	12	6.4	103	506	111	2.1	15	57	5.7	830

[1] 150 treatment plants from cities in northeast and north central states (Sommers, 1977).
[2] Treatment plants from 40 cities (USEPA, 1989).
[3] Data for Cd, Cr, Cu, Pb, Ni, and Zn are from 62–64 U.S. treatment plants; As, Hg, Mo, and Se are from 37, 50, 12, and 30 plants, respectively (Pietz et al., 1998).
[4] 199 treatment plants from cities throughout the U.S. (USEPA, 1990).
[5] 203–210 treatment plants from cities throughout the U.S. (Pietz et al., 1998).

Source: Page and Chang, 1998.

Trace Elements, Heavy Metals, and Micronutrients

Biosolids contain trace elements, including heavy metals, primarily from industrial, commercial, and residential discharges into the wastewater system. As a result of the Clean Water Act of 1972 which restricted industrial discharge, the quality of the wastewater entering publicly owned wastewater treatment plants has improved significantly. In 1989, USEPA published data from 40 cities. Table 2.1 shows the changes in heavy metals as related to the 503 regulations. In the 40 cities study, cadmium (Cd) and lead (Pb) could not meet the Part 503 pollution limits. The effect of industrial pretreatment and regulations can be seen in Table 2.2. These data show the changes that have occurred from 1976 to 1996. Cadmium decreased from 110 mg/kg dry weight in 1976 to 6.4 mg/kg dry weight in 1996. The biggest change occurred after 1987. Similarly, large reductions occurred with the other heavy metals with the exception of copper (Cu). Copper did not change, probably since much of

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the copper entering wastewater treatment plants is from use of copper piping in the domestic system.

The addition of chemicals such as lime and ferric chloride can affect pH, composition, and chemical species. The chemical species could influence solubility and hence mobility in the soil or uptake by plants. The method of biosolids processing and stabilization also affects their characteristics (Richards et al., 1997). The authors evaluated the leachability of trace elements as indicated by the toxic characteristic leaching procedure (TCLP) of dewatered, composted, N-Viro, pellets, and incinerator ash. TCLP is commonly used to indicate potential leachability of metals. The data in Table 2.3 show that, with the exception of N-Viro, very small percentages of Cd, Cr, Cu, Mo, Ni, Pb, and Zn were extracted as a percentage of total content. This indicates that the potential for leaching and mobility in the soil is extremely low. State regulators that require the TCLP for biosolid products do not understand that this does not provide any information on mobility of heavy metals from composted and other products where the organic matter binds the heavy metals. It is applicable to salts. Also this procedure does not indicate uptake by plants.

Changes in materials used in domestic residences have also affected wastewater quality. Lead was used in early plumbing and is now prohibited. Copper piping has contributed Cu, especially when domestic water had a low pH. Considerable copper piping has reverted to plastic piping. Another source of heavy metals is from the food we eat and discharge of food materials into the wastewater stream. This is especially true where disposals are used.

Trace elements and heavy metals are ubiquitous. They are found in natural soils and plants. They are also in fertilizers since they are part of the mineralogical composition of the mined materials. This is especially true of many phosphate fertilizers that could contain high levels of cadmium and zinc. Raven and Loeppert (1997) analyzed 16 fertilizer materials. Three were primarily nitrogen (ammonium) products; eight were phosphate materials, and four were potassium sources. They also analyzed sewage sludge, organic materials, and liming materials. Among the fertilizers, phosphate sources had the highest heavy metals. Potassium and nitrogen fertilizers had insignificant amounts. Cadmium in phosphate fertilizers ranged from 0.7 to 48.8 mg/g; Cu from 0.68 to 19.6 mg/g; Ni from 0.6 to 50.4 mg/g; Pb from <0.2 to 29.2 mg/g, and Zn from not detected to 33.5. They concluded that trace and heavy metal concentrations generally decreased in this order: rock phosphate > biosolids > commercial phosphate fertilizer > organic amendments and liming material > commercial K fertilizers > commercial N fertilizers. As early as 1975, Lee and Keeny (1975) estimated that 2150 kg of Cd is added annually to Wisconsin soils through fertilizers and biosolids, with much more coming from fertilizers than biosolids.

Organic Compounds

Organic compounds are found in biosolids as a result of industrial and commercial discharges, household discharges, pesticides from runoff and soil. In 1980, USEPA reported on the occurrence and fate of 129 priority pollutants in the waste-

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Table 2.3 Effect of Biosolids Stabilization on TCLP Extractability of Some Trace Elements

Trace Element	Dewatered Total	Dewatered Extract	Compost Total	Compost Extract	N-Viro Total	N-Viro Extract	Pellets Total	Pellets Extract	Ash Total	Ash Extract
					Mean Concentration - mg/kg					
Cd	5.62	ND	4.21	0.17	1.58	0.11	6.43	0.51	3.58	0.15
Cr	130	1.85	121	1.35	40	0.97	135	1.92	218	1.18
Cu	587	0.98	469	9.75	119	51.0	606	23.0	1219	21.5
Mo	49.7	0.56	32.7	0.55	9.8	4.93	55.3	1.50	95.1	4.52
Ni	35.8	2.54	32.5	1.58	12.7	3.07	38.0	5.84	74.8	3.66
Pb	132	0.81	109	0.10	NA	0.61	137	0.08	145	0.08
Zn	545	60.9	458	52.5	115	ND	567	84.7	959	39.1

NA = not available.

Source: Richards et al., 1997.

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Table 2.4 Priority Pollutants Present in Combined Undigested Sewage Sludges at 20 Wastewater Plants

Organic Chemical	No. Times Detected	Concentration in Sludges			
		µg/l, Wet		mg/kg, Dry	
		Median	Range	Median	Range
Bis (2-ethylhexyl) phthalate	13	3806	157–11257	109	4.1–273
Chloroethane	2	1259	517–2000	19	14.5–24
1,2-*trans*-Dichloroethylene	11	744	42–54993	21	0.72–865
Toluene	12	722	54–26857	15	1.4–705
Butylbenzyl phthalate	11	577	1–17725	15	0.52–210
2-Chloronaphthalene	1	400	400	4.7	4.7
Hexachlorobutadiene	2	338	10–675	4.3	0.52–8
Phenanthrene	12	278	34–1565	7.4	0.89–44
Carbon tetrachloride	1	270	270	4.2	4.2
Vinyl chloride	3	250	145–3292	5.7	3–110
Dibenzo(a,h)anthracene	1	250	25	13	13
Naphthalene	9	238	23–3100	7.5	0.9–70
Ethylbenzene	12	248	45–2100	5.5	1.0–51
Di-*n*-butylphthalate	12	184	10–1045	3.5	0.32–17
Phenol	11	123	27–4310	4.2	0.9–113
Methyl chloride	10	89	5–1055	2.5	0.06–30
Pyrene	12	125	10–734	2.5	0.33–18
Chrysene	9	85	15–750	2.0	0.25–13
Fluoroanthene	10	90	10–600	1.8	0.35-–7.1
Benzene	11	16	2–401	0.32	0.053–11.3
Tetrachloroethylene	11	14	1–1601	0.38	0.024–42
Trichloroethylene	10	57	2–1927	0.98	0.048–44

Source: Naylor and Loehr, 1982, *BioCycle* 23(4): 18–22. With permission.

water and sludge from 20 publicly owned wastewater treatment plants in the United States. Although the survey included small treatment plants, the median flow was 30.4 MGD, which represented a population of approximately 300,000 people (Naylor and Loehr, 1982). Table 2.4 shows the organic priority pollutants present in combined undigested sewage sludges. Combined sludges consisted of a mixture of sludges generated by two or more wastewater treatment processes (e.g., primary plus secondary sludges). The authors felt that these data represented a conservative (high) estimate of the actual amounts of organic priority pollutants, since no losses could have occurred from digestion.

Jacobs et al. (1987) published an extensive list of organic chemicals found in sewage sludges and biosolids. Table 2.5 is a summary of the data by chemical group. As they indicated, sewage sludges and biosolids can be highly contaminated with organic compounds. These data were cited prior to the implementation of industrial pretreatment.

Subsequently, in 1990, USEPA published the results of the National Sewage Sludge Survey that determined the chemical constituents in 209 wastewater treatment plants randomly selected throughout the United States. The number of treatment plants in which organic compounds were detected and the concentration of these compounds were very low. Several of the pesticides, such as DDT and chlordane, have been banned

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Table 2.5 Summary of Distribution of Organic Chemicals in Sewage Sludges and Biosolids by Chemical Groups

Chemical Group[1]	No. of Organic Chemicals Tested	No. of Organic Chemicals Tested Having Median Concentrations in Sludges and Biosolids mg/kg Dry Weight Basis				
		ND	<1	1-10	1-100	>100
Phthalate esters	6	0	0	1	4	1
Monocyclic aromatics	26	12	5	2	4	0
Polynuclear aromatics	7	0	4	2	1	0
Halogenated biphenyls	9	1	3	5	0	0
Halogenated aliphatics	10	0	6	4	0	0
Triaryl phosphate esters	3	0	0	2	1	0
Aromatic and alkyl amines	16	6	9	0	1	0
Phenols	12	0	1	11	0	0
Chlorinated pesticides and hydrocarbons	21	4	14	3	0	0
Miscellaneous	2	1	0	1	0	0
Totals	**109**	**24**	**42**	**31**	**11**	**1**

[1] There was inadequate data on dioxins and furans.

Source: Jacobs et al., 1987, pp. 101–143, A.L. Page et al., (Eds.), *Land Application of Sludge*, Lewis Publishers, Chelsea, MI. With permission.

from application and are no longer manufactured. Similarly PCBs are not being manufactured. However, both DDT and PCBs are very persistent in the environment.

The study gathered data at 180 publicly owned treatment works (POTWs), as well as survey data from 475 public treatment facilities with at least secondary wastewater treatment in the United States. USEPA screened 412 pollutants. These included dioxins/furans, pesticides, herbicides, semivolatile and volatile organic compounds. USEPA reviewed the scientific literature for toxicity, fate, effect, and transport information. The data showed extremely low levels; therefore, toxic organics were excluded from the 40 CFR 503 regulations. The data for the regulated priority pollutants are shown in Table 2.6 (USEPA, 1990). With the exception of Bis (2-ethylhexyl) phthalate, the other organics were essentially not detected. One reason for the low detection is the rather high detection limits.

Another group of organic chemicals of concern is surfactants, which are derived from detergent products, paints, pesticides, textiles, and personal care products (La Guardia et al., 2001). They are very abundant in biosolids, and concentrations range from 200 to 20,000 mg/kg dry weight (Haig, 1996). Three types of surfactant compounds (WEAO, 2001) are:

1. Anionic, e.g., linear alkylbenzene sulfonates (LAS), alkane ethoxy sulfonates (AES), secondary alkanesulfonates (SAS)
2. Nonionic, e.g., alcohol ethoxylates (AE), alkylphenols (AP), including alkylphenol polyethoxylates (APE)
3. Cationic, e.g., di-2-hydroxyethyl dimethyl ammonium chloride (DEEDMAC, quaternary esters)

Linear alkylbenzene sulfonates and alkylphenols are the most common surfactant compounds. Alkylphenols are endocrine disrupters. 4-Nonylphenols (NPs) are com-

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Table 2.6 Organic Compounds Found in Biosolids

Organic Compound	Number of Times Detected	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)
Aldrin	8	0.029	0.019	0.046
Benzene	4	0.098	0.012	0.220
Benzo(a)pyrene	7	10.785	0.671	24.703
Bis(2-ethylhexyl)phthalate	189	107.233	0.510	89.129
Chlordane	1	0.489	0.489	0.489
4,4' –DDD	1	0.391	0.391	0.391
4,4' –DDE	4	0.100	0.030	0.190
4,4' –DDT	7	0.051	0.015	0.121
Dieldrin	6	0.024	0.013	0.047
Dimethyl nitrosamine	0	BDL[1]	BDL	BDL
Heptachlor	1	0.023	0.023	0.023
Hexachlorobenzene	0	BDL	BDL	BDL
Hexachlorobutadiene	0	BDL	BDL	BDL
Lindane (Gamma-BHC)	2	0.074	0.072	0.076
PCB-1016	0	BDL	BDL	BDL
PCB-1221	0	BDL	BDL	BDL
PCB-1232	0	BDL	BDL	BDL
PCB-1242	0	BDL	BDL	BDL
PCB-1248	23	0.740	0.043	5.203
PCB-1254	13	1.765	0.312	9.347
PCB-1060	20	0.671	0.031	4.006
Toxaphene	0	BDL	BDL	BDL
Trichloroethylene	7	0.848	0.024	3.302

[1] BDL = Below detection limit.

Source: USEPA, 1990

mon products of biodegradation of many nonionic surfactants, the nonylphenol ethoxylates (NPEs).

Guenther et al., (2002) analyzed 60 different food materials commonly available in Germany. They found that NPs were ubiquitous in foods. The concentrations of NPs ranged from 0.1 to 19.4 µg/kg wet weight basis, regardless of the fat content. They indicated that many of the sources in foods could be from packaging, cleaning agents, and pesticides. It is therefore not surprising that these compounds, in addition to entering the wastewater treatment plant from commercial and industrial sources, would also be deposited from food waste.

Some surfactants are biodegraded during biological treatment. Jensen (1999) reported that LAS compounds degrade very slowly or not at all under anaerobic conditions. Since more than 90% are removed from the liquid phase during wastewater treatment, significant amounts can be found in the solids portion. La Guardia et al. (2001) analyzed 11 biosolids and biosolid products, four Class A and seven Class B biosolids, for alkylphenol ethoxylate degradation products. These included octylphenol (OP), nonylphenols (NPs), nonylphenol monoethoxylates (NP1EOs) and nonylphenol diethoxylates (NP2EOs). As the authors indicate, these compounds are toxic and are endocrine disrupters.

Table 2.7 summarizes their data. In 10 of the 11 biosolids, nonylphenols were the most abundant of the byproducts. The mean concentration (722 mg/kg) in the

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Table 2.7 Concentration of Alkyphenol Ethoxylate Degradation Products in Biosolids

Biosolid	Octylphenol	Nonylphenols	Nonylphenol Monoethoxylates	Nonylphenol Diethoxylates	Total
			mg/kg		
Class A					
Compost A	<0.5	5.4	0.7	<1.5	6.1
Compost B	1.5	172	2.5	<1.5	176
Compost C	<0.5	14.2	<0.5	<1.5	14.2
Heat dried	7.5	496	33.5	7.4	544
Class B					
Lime A	5.3	820	81.7	25.3	932
Lime B	2.0	119	154	254	529
Anaerobically digested	9.9	683	28.4	<1.5	721
Anaerobically digested	12.6	720	25.7	<1.5	758
Anaerobically digested	11.0	779	102	32.6	925
Anaerobically digested	11.7	707	55.8	<1.5	768
Anaerobically digested	6.7	8.7	64.9	22.7	981

Source: La Guardia et al., 2001.

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anaerobically digested biosolids was nearly twice that of the heat-dried biosolids (496 mg/kg) and lime stabilized biosolids (470 mg/kg) and 12 times greater than the composted biosolids (64 mg/kg). The authors suggest that the lower values in the compost could be the result of dilution with bulking agents and further aerobic degradation. They report that degradation is greater under aerobic than anaerobic conditions.

Bennie (1999) reviewed the environmental occurrence of alkylphenols and alkylphenol ethoxylates in biosolids in Canadian wastewater treatment plants. He reported that the concentrations ranged from not detected (ND) to 850 mg/kg. The concentration of 4-NP ranged from 8.4 to 850 mg/kg; NP1EO from 3.9 to 437 mg/kg; NP2EO from 1.5 to 297; and NPnEO from 9 to 169. Octyl phenolics ranged from not detected to 20 mg/kg (Bennie, 1999; WEAO, 2001).

Another group of compounds found in biosolids that may be toxic to humans and animals is brominated diphenyl ethers (BDEs or PBDEs). Hale et al. (2001) examined 11 biosolid samples from California, New York, Virginia, and Maryland. The total concentrations ranged from 1,100 to 2,290 µg/kg dry weight basis. These are environmentally persistent compounds that have been found to bioaccumulate and be toxic in the aquatic environment. At the present time, the risk to humans is unknown.

One of the most toxic chemicals to animals and humans purportedly is a group of compounds termed dioxins. Dioxins are a group of congeners of chlorinated dibenzo-*p*-dioxins and dibenzofurans (Thomas and Spiro, 1996). Dioxins are ubiquitous and humans are exposed to them on a daily basis. In Round Two of the regulations, dioxins and some other organic compounds are being evaluated. This evaluation includes 29 specific congeners of polychlorinated dibenzo-*p*-dioxins, polychlorinated dibenzofurans, and coplaner polychlorinate biphenyls (PCBs). The agency is proposing a limit of 300 parts per trillion (ppt) toxic equivalents (TEQ) or nanograms TEQ per kilogram of dry biosolids.

Internationally, the median values of dioxin in sewage sludge generally ranges between 20 to 80 ng/kg TEQ (Carpenter, 2000). Jones and Sewart (1997) provided a comprehensive review of dioxins and furans in sewage sludges. They reported on the TEQ content of sewage sludges and biosolids from various countries. Their data are shown in Table 2.8.

Radionuclides may enter the sewage treatment plant principally as a result of discharges from medical facilities. They are relatively short lived (i.e., a short half-life). WEAO (2001) reported the medically used radionuclides most frequently observed were gallium-67, indium-111, iodine-123, iodine-131, thallium-201 and technetium-99.

Acidity (pH)

The pH of most biosolids — whether liquid, semisolid, or solid — is generally in the range of 7 to 8, unless lime is added during the wastewater treatment process. Lime, kiln dust and other alkaline products may be added to increase the pH and achieve the USEPA pathogen requirements. In some cases, such as in the biosolids

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Table 2.8 Concentration of Dioxin in Sewage Sludges from Various Countries

Country	Number of Samples	Concentration – ng/kg Dry Weight		Source
		Range	Mean	
Germany	28	28–1560	102	Hagenmaier, 1988
Germany	13	20–177	47	Hagenmaier et al., 1992
Sweden	4	82–266	160	Broman et al., 1990
United States	239	0.49–2321	83	USEPA, 1990
England	11		150–200	DoE, 1989
England	16			DoE, 1993
Rural		9–73	23.3	
Mixed ind/rural		29–67	42.5	
Light ind/domestic		21–105	42.3	
Ind/domestic		7.6–192	52.8	
England	8	19–206	72	Sewart et al., 1995
Switzerland	30	6–4100	357	Rappe et al., 1994

Source: Jones and Sewart, 1997, *Crit. Rev. Environ. Sci. Technol*. 27(1): 1–85. With permission.

Table 2.9 Median Concentration of Several Macronutrients

Nutrient	Type of Biosolid			All Biosolids
	Anaerobic	Aerobic	Other	
% N	4.2	4.8	1.8	3.3
% P	3.0	2.7	1.0	2.3
% K	0.3	0.4	0.2	0.3
% Ca	4.9	3.0	3.4	3.9
% Mg	0.5	0.4	0.4	0.4
% Fe	1.2	1.0	0.1	1.1

Source: Sommers, 1977, *J. Environ. Qual*. 6: 225–232. With permission.

from the Washington, D.C. Blue Plains wastewater treatment plant, lime was added to reduce odors and avoid vectors during shipment to the composting facility at Site II in Maryland.

Plant Nutrients

Plant nutrients are among the most important chemical characteristics of biosolids. Farmers value biosolids for the nitrogen and phosphorus content. Because of this important characteristic, Chapter 3 is devoted to plant nutrients.

The major plant nutrients are nitrogen (N), phosphorus (P) and potassium (K). Other macronutrients are calcium (Ca), magnesium (Mg), and iron (Fe**)**. Table 2.9 shows early data by Sommers (1977) for anaerobic, aerobic, and other biosolids. The other category included data from lagoons, primary, tertiary, and unspecified biosolids.

These early data do not reflect the use of alkaline products, which would increase the Ca and Mg content. Furthermore, during that period, ferric chloride and lime

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Table 2.10 Plant Nutrients in Sewage Sludge and Biosolids from Several Cities

Plant Nutrient	Albuquerque 1987–1991	HRSD 1984–1991	MMSD 1989–1992	Denver 1983–1992	Chicago 1987–1990
% TKN	3.98–5.84	NA	7.4–10.6	4.9–9.5	7.83–8.85
% Organic N	NA	2.36–5.04	NA	NA	NA
% P	NA	1.72–3.0	2.5–2.8	2.12–3.4	8.32–10.89
% K	NA	0.14–0.28	0.6–1.0	0.30–0.50	1.08–2.24
% Ca	NA	NA	NA	NA	37.7–58.8
% Mg	NA	4.58–7.68	NA	NA	16.9–22.0
% Fe	9.29–17.7	NA			18.7–28.4

1987, 1988 data missing.

NA = Not available.

Source: Adapted from Stukenberg et al., 1993.

were used in dewatering, which was principally done by vacuum filters. Today belt filter presses and centrifuges predominate and use polymers. Consequently the concentration of Fe, Ca, and Mg would probably be lower. Later data for several biosolids are shown in Table 2.10.

BIOLOGICAL PROPERTIES

Microbiological

Pathogens, the most important biological property of biosolids for land application, are discussed in detail in Chapter 8. Another important characteristic is the indigenous microbial population. This population enhances the soil biota that is very important in organic matter decomposition and soil physical properties.

Many microbes and other organisms are involved in the decomposition process. There is very little data on this subject. This indigenous population consists of bacteria, fungi, actinomycetes, and protozoa. It has been reported that fresh animal manures may contain 10^6 anaerobic bacteria, 10^5 coliform bacteria, 10^6 enterococci bacteria, and 10^5 fungi per ml of suspension (Parr, 1974).

It is very possible that similar numbers are found in biosolids. Miller (1973) reported that application of biosolids increases the soil microbial population. Bacteria, actinomycetes, and fungi increased during the decomposition of anaerobically digested biosolids. Numbers of bacteria and actinomycetes were directly related to biosolids' loading rates. The increase in the fungal population was not as pronounced. A significant finding in this early study showed a change in the bacterial population from one dominated by Gram-positive bacteria in the unamended soil to one where Gram-negative bacteria were greater than 50%.

Organic Matter

Organic matter is an important constituent of biosolids. The use of biosolids for land application enhances the organic content of the soil. This is most important in

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sandy or clayey soils. In sandy soils the organic matter increases the water-holding capacity, soil aggregation, and other soil physical properties. It reduces the soil bulk density. Also, organic matter increases the cation exchange capacity, a very important property for supplying plant nutrients. The positive effect on the soil physical properties enhances the plant root environment. Plants are better able to withstand drought conditions, extract water, and utilize nutrients.

One of the earliest studies on the value of the organic matter content of biosolids was reported by Lunt (1953). He indicated that anaerobically digested biosolids provided modest increases (3% to 23%) in field moisture capacity, non-capillary porosity, and cation exchange capacity. The organic matter content increased by 35% to 40% and soil aggregation by 25% to 600%. The greatest increases occurred with a sandy soil, and less with loams.

Epstein (1973, 1975) indicated that organic matter through the activity of microorganisms increases soil aggregation. Biosolid application increased the stable aggregates 16% to 33%. The addition of 5% sludge and biosolids increased the amount of water retained at different suction values. Adding biosolids and sludge increased the hydraulic conductivity of soils. Clapp et al. (1986) indicated that organic matter through the addition of biosolids reduced bulk density and increased total porosity and moisture retention of soils.

Lindsay and Logan (1998) evaluated the effect of anaerobically digested biosolids on soil physical properties when applied to a silt loam soil. They reported that bulk density significantly decreased, and porosity, moisture retention, percentage water stable aggregates, mean weight diameter of aggregates, liquid, and plastic limits increased with increasing biosolids application. Organic C increased linearly with biosolids application, and 4 years after application there was three times as much C in the high biosolids application rate. They concluded that the observed differences in soil physical properties are due to the effects of added organic matter and that these effects persisted for at least 4 years.

CONCLUSION

Pretreatment of industrial wastes discharged into domestic sewers has substantially reduced the levels of trace elements and heavy metals. USEPA regulations limiting heavy metal application to soils has also forced municipalities to enforce industrial and commercial discharges. Today, most biosolids have lower concentration of heavy metals than levels specified by USEPA in the 503 regulations. Domestic waters are major contributors of copper, especially in regions where the water entering homes is acidic.

Organic compounds are very low in biosolids. Furthermore, many organic compounds will be biodegraded in the soil. Organic compounds, because of their size, are generally not taken up by plant roots and translocated to the above-ground edible crop.

Biosolids enhance the microbial population, which increases the rate of organic matter decomposition in soils. As a result, there is a significant change in the soil

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physical properties. This produces a marked improvement in the plant root environment and better plant growth.

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